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**NAME OF THE TRANSLATOR** : Eun-Ae LEE

**SIGNATURE** : Eun-Ae LEE

**Date** : September 21, 2006

**RESIDENCE** : MIHWA BLDG., 110-2, MYONGRYUN-DONG 4-GA, CHONGRO-GU, SEOUL 110-524, KOREA

**CITIZENSHIP** : REPUBLIC OF KOREA

*Translation of Priority Document*

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Application Number : Korean Patent Application No. 1999-26862

Date of Application : July 5, 1999

Applicant(s) : Samsung Electronics Co., Ltd.

September 21, 2006

**COMMISSIONER**

# [ABSTRACT OF THE DISCLOSUSRE]

## [ABSTRACT]

An apparatus of compensating for a frequency offset using a guard interval and a pilot symbol, which are inserted at a transmitter, in an OFDM (Orthogonal Frequency Division Multiplexing) system. The OFDM system receives an OFDM signal in which a pilot symbol is inserted in data of a frame unit at regular intervals and a guard interval is inserted in a data symbol. In the system, a first carrier synchronizer receives a data symbol stream obtained by converting the OFDM signal to digital data, and detects a guard interval of each data symbol, to compensate for a coarse frequency offset. A fast Fourier transform part OFDM-demodulates a signal output from the first carrier synchronizer. A second carrier synchronizer detects the pilot symbol from the demodulated data symbol stream to compensate for a fine frequency error.

## [REPRESENTATIVE FIGURE]

FIGURE 5

## [INDEX]

Pilot Symbol, Frequency Offset Compensation

# [SPECIFICATION]

## [TITLE OF THE INVENTION]

APPARATUS OF COMPENSATING FOR FREQUENCY OFFSET USING PILOT SYMBOL IN AN ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING SYSTEM

## [BRIEF DESCRIPTION OF THE DRAWINGS]

FIG. 1 is a diagram illustrating a structure of a general OFDM/CDMA system;

FIG. 2 is a diagram illustrating a data structure using pilot samples in a general OFDM/CDMA system;

FIG. 3 is a diagram illustrating a structure of a transmitter in an OFDM/CDMA system according to an embodiment of the present invention;

FIG. 4 is a diagram illustrating a pilot symbol-inserted frame structure in an OFDM/CDMA system according to an embodiment of the present invention;

FIG. 5 is a diagram illustrating a structure of a receiver in an OFDM/CDMA system according to an embodiment of the present invention;

FIG. 6 is a diagram illustrating a detailed structure of the first carrier synchronize of FIG. 5; and

FIG. 7 is a diagram illustrating a detailed structure of the second carrier synchronizer of FIG. 5.

## [DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT]

## [OBJECT OF THE INVENTION]

## [RELATED FIELD AND PRIOR ART OF THE INVENTION]

The present invention relates generally to a frequency offset compensation apparatus for an OFDM/CDMA (Orthogonal Frequency Division Multiplexing/Code Division Multiple Access) system, and in particular, to a frequency offset compensation apparatus which compensates for a frequency offset (or frequency error) using a guard interval and a pilot symbol.

As the types of the recent multimedia services are diversified, it is necessary to transmit data at high speed. In addition, as the user's demand for construction of a wireless network increases, a wireless asynchronous transmission mode (hereinafter, referred to as "WATM") market is expanded. Thus, every country forms various organizations for WATM standardization to expedite implementation of the WATM technology. For implementation of such a high-speed data transmission technology, active researches are being carried out on a method for using the orthogonal frequency division multiplexing (hereinafter, referred to as "OFDM") technology in implementing the high-speed data transmission. In the OFDM technology, data is transmitted on a plurality of subcarriers after inverse fast Fourier transform (IFFT), and the transmitted subcarriers are converted to the original data in an OFDM receiver through fast Fourier transform (FFT).

FIG. 1 illustrates a structure of a general OFDM/CDMA system. With reference to FIG. 1, a description will be made of the structure and operation of a transceiver in the OFDM/CDMA system.

First, the structure of a transmitter will be described. A spreader 101 spreads data symbol streams to be transmitted by multiplying the data symbol streams by a code of an N rate in a data symbol unit. Herein, N data bits obtained by multiplying the data symbol by the code of N rate will be referred to as "data samples". The N data samples spread from the data symbol are parallelized by a serial-to-parallel (S/P) converter 103 and then, input to a pilot sample inserter 105. The pilot sample inserter 105 receives the N data samples in parallel, punctures the received data samples at regular intervals, and then inserts pilot data samples as shown in FIG. 2, and the pilot sample-inserted data symbol is provided to an inverse fast Fourier transform (IFFT) section 107. The IFFT 107 receives in parallel the pilot sample-inserted data samples in the data symbol unit and performs inverse fast Fourier transform on the received data samples. In the following description, the IFFT-transformed data output from the IFFT 107 will be referred to as "OFDM symbol". The OFDM symbol is also comprised of N data samples. The OFDM symbol output from the IFFT 107 is input to a guard interval inserter 109. The guard interval inserter 109 copies a part of the rear end of the received OFDM symbol and inserts it in the front of the OFDM symbol. The guard interval-inserted OFDM symbol is converted to an analog OFDM symbol by a digital-to-analog converter (DAC) 111 and the converted analog OFDM symbol is transmitted after up-conversion.

Next, a receiver down-converts the analog signal transmitted from the transmitter. Because of the inaccuracy of an oscillator used during the down-conversion, the baseband signal includes a frequency offset. The analog signal is converted to a digital OFDM symbol by an analog-to-digital converter (ADC) 121 and then, applied to a guard interval remover 123. The guard interval remover 123 frame-synchronizes the OFDM symbol output from the ADC 121, and after frame synchronization, removes the guard interval included in the OFDM symbol, the guard interval-removed OFDM symbol being applied to a fast Fourier transform (FFT) section 125. The FFT 125 FFT-transforms the OFDM symbol output from the guard interval remover 123 and outputs a data symbol. At this point, since a signal is obtained which is shifted by the frequency offset included during the down-conversion, it is difficult to recover the original data. Particularly, in an OFDM/CDMA system where a desired signal is carried at each frequency band, the frequency offset should be correctly estimated and compensated for to recover the original signal. To compensate for the frequency offset, a carrier synchronizer 127 detects a pilot sample from the data symbol output from the FFT 125, and performs carrier synchronization using the detected pilot sample. A despreader 129 despreads the data symbol output from the FFT 125, which was spread into N data samples, and outputs the original data symbol.

The FFT 125 generally recovers the frequency offset using the FFT characteristics shown in Equation (1) below.

$$X[n]W_N^{K_0 n} \leftrightarrow X[k-k_0](W_N = e^{\frac{-j2\pi}{N}}) \ldots\ldots. (1)$$

where X[n] is an input signal in a time domain, which is input to the FFT, $W_N^{K_0 n}$ is an offset term, and X[k-$k_0$] denotes a received signal with a frequency offset, which is shifted by $k_0$ from the transmission signal during down-conversion.

FIG. 2 illustrates a data structure used in the general OFDM/CDMA system, which shows that the pilot data samples are inserted after puncturing N data samples for each data symbol in a specific pattern. Since the pilot data samples are inserted in a specific pattern, Equation (1) is calculated using the pilot data samples and the frequency offset is compensated for by calculating a shift amount $k_0$ of the data calculated by Equation (1).

In an ideal system, since the pilot samples received as shown in Equation (1) are received in a position shifted by $k_0$ samples from the original reference sample position, it is possible to calculate the frequency offset $k_0$ by estimating the shifted value using a correlator. However, in the OFDM/CDMA system, use of the above pilot samples causes such performance degradation as an increase of over 2 times in a data rate, complication of a receiving stage for compensating for the frequency offset, and an increase in a noise level, so that it is difficult to use the pilot samples.

A non-ideal system has the more serious problems. The factors affecting the IFFT-transformed signal include a timing error, a common phase error (CPE)

and the noises. In the receiver, a timing error $n_e$ in a time domain, after passing the FFT stage, are expressed by the product of the original signal in the frequency domain and an exponential term. This ultimately affects even the pilot sample value, so that an increase of this value may cause considerable performance degradation of the correlator. Therefore, in the OFDM/CDMA system, it is difficult for the conventional frequency offset compensation method to detect a correct frequency offset value.

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**[SUBSTANTIAL MATTER OF THE INVENTION]**

It is, therefore, an object of the present invention to provide a transmitter which inserts pilots (or pilot symbols) of a symbol unit at regular intervals when transmitting a data symbol steam, to enable exact frequency offset correction at a receiver.

It is another object of the present invention to provide a frequency offset compensation apparatus which compensates twice for a frequency offset using a guard interval and a pilot symbol included in received frame data in which pilot symbols are inserted at regular intervals.

To achieve the above object, a transmitter for an OFDM system includes a modulator for OFDM-modulating a received data symbol, a guard interval inserter for inserting a guard interval in the OFDM-modulated data symbol, a pilot symbol inserter for inserting a pilot symbol in the data of frame unit output from the guard interval inserter at regular intervals, and an analog-to-digital

converter for converting the data output from the pilot symbol inserter to an analog signal.

To achieve another object, a receiver for an OFDM system, which receives an OFDM signal for which a pilot symbol is inserted in data of a frame unit at regular intervals and a guard interval is inserted in a data symbol, includes a first carrier synchronizer for receiving a data symbol stream obtained by converting the OFDM signal to digital data and compensating for an approximate frequency offset by detecting the guard interval of each data symbol, a fast Fourier transform section for OFDM-demodulating the signal output from the first carrier synchronizer, and a second carrier synchronizer for compensating for a fine frequency offset by detecting the pilot symbol from the demodulated data symbol stream.

## [CONSTRUCTION AND OPERATION OF THE INVENTION]

A preferred embodiment of the present invention will be described herein below with reference to the accompanying drawings. In the following description, well-known functions or constructions are not described in detail since they would obscure the invention in unnecessary detail.

In an exemplary embodiment of the present invention, a guard interval and a pilot symbol are used to estimate a frequency offset in such actual states as timing error, common phase error and noises. A structure of a transmitter for

inserting the guard interval and the pilot symbol before transmission will be described below with reference to FIG. 3.

A serial-to-parallel (S/P) converter 201 receives in series a data symbol, which is spread with a code of length N and comprised of N data samples, and outputs the N data samples in parallel. A pilot symbol inserter 203 receives in parallel the N data samples from the S/P converter 201, and inserts pilot symbols in a frame in a specific pattern before transmission. The pilot symbol inserter 203 can be comprised of means (not shown) for generating the pilot symbol and switching means (now shown) for switching the data symbol and the pilot symbol according to a specific pattern. The switching means can be comprised of a multiplexer. The pilot symbol inserter 203 can also be positioned in a preceding stage of the S/P converter 201. An inverse fast Fourier transform (IFFT) section 205 receives in parallel the N data samples output from the pilot symbol inserter 203, performs inverse fast Fourier transform on the received data samples, and outputs the IFFT-transformed OFDM symbol to a parallel-to-serial (P/S) converter 207. The IFFT-transformed OFDM symbol is comprised of N data samples. Since the N data samples of the OFDM symbol are OFDM-modulated in the data symbol unit, those are different from the N data samples before the IFFT operation. The P/S converter 207 serializes the IFFT-transformed N data samples and outputs them to a guard interval inserter 209. The guard interval inserter 209 copies a part of the rear end of the OFDM symbol output from the P/S converter 207, and inserts it in the front of the data symbol. In the following description, it will be assumed that the number of data samples in the guard

interval is N (the number of data samples) × 1/2.

A pilot symbol inserter 211 wherein a data symbol where a guard interval is inserted from the guard interval inserter 209 includes a pilot symbol pattern, and inputs and inserts the pilot symbol at regular intervals. A data symbol and a pilot symbol is converted an analog symbol by a digital-to-analog converter (ADC) 221 and the converted analog symbol is transmitted after up-conversion.

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FIG. 4 illustrates a pilot symbol-inserted frame structure in an OFDM/CDMA system according to an embodiment of the present invention, wherein the pilot symbols are inserted at intervals of 4 data symbols. The pilot symbols can also be inserted in one frame at regular intervals or inserted at regular intervals without frame separation.

FIG. 5 illustrates a structure of a receiver in an OFDM/CDMA system according to an embodiment of the present invention.

In actual circumstances, the receiver of the OFDM/CDMA system has the frequency offset, the common phase error, the noises and the timing error. The signals received in the actual circumstances should be modeled. As illustrated in FIG. 3, if it is assumed that the signal at the input end of the IFFT 205 in the transmitter of the OFDM/CDMA system is $X_m(k)$ and the signal passed the IFFT 205, in which the guard interval is not inserted yet, is $X_m[n]$, a signal FFT-transformed by the receiver after removing $y'_m[n]$ and the guard

interval from an analog-to-digital converted signal will be defined as $Y'_m[k]$ in the following description.

If a frequency offset per symbol is $k_e$ [Hz/symbol], then a frequency offset per sample is $k_e/N$ [Hz/sample] and a frequency offset $k_m[n]$ of an $n^{th}$ sample of an $m^{th}$ symbol is expressed by Equation (2) below.

$$k_m[n] = \frac{k_e}{N} m\{N + G\} + \frac{k_e}{N} n \quad \ldots\ldots\ (2)$$

where G denotes the number of samples in the guard interval.

In the receiver, a signal $y_m[n]$ including the frequency offset, the common phase error and the noises is expressed by Equation (3) below, in which for convenience, the number of samples is given from –G to N-1.

$$\begin{aligned} y_m[n] &= X_m[n] \cdot e^{j2\pi k_m[n]} \cdot e^{jP_e} + W_m[n] \\ &= X_m[n] \cdot e^{\frac{j2\pi k_e[m\{N+G\}+n]}{N}} \cdot e^{jP_e} + W_m[n] \\ &= X_m[n] \cdot e^{j2\pi k_e \frac{n}{N}} \cdot e^{\frac{j2\pi k_e m\{N+G\}}{N}} \cdot e^{jP_e} + W_m[n] \quad \ldots\ldots\ (3) \end{aligned}$$

where $P_e$ denotes the common phase error and $W_m[n]$ denotes AWGN (Additive White Gaussian Noise) of the $m^{th}$ symbol.

Now, the structure and operation of the receiver will be described with reference o FIG. 5. An analog-to-digital converter (ADC) 221 down-converts the analog signal transmitted from the transmitter and converts the down-converted analog signal to a digital OFDM symbol. In the following description, the signal output from the ADC 221 will be defined as $y'_m[n]$. A first carrier synchronizer 223 is a carrier synchronizer which uses the guard interval. The first carrier synchronizer 223 receives the OFDM symbol output from the ADC 221, detects a guard interval G of the FODM symbol and G data samples (hereinafter, referred to as copied data samples) at the rear end of the data symbol used to insert the guard interval, and performs frequency synchronization by compensating for the frequency offset of the OFDM symbol output from the ADC 221 using the guard interval and the data samples copied to generate the guard interval. In the embodiment of the present invention, the number G of the data samples in the guard interval is 1/2 the number N of the data samples of the data symbol. If a signal of the guard interval, i.e., the guard interval comprised of the G data samples inserted in the front of the $m^{th}$ OFDM symbol is defined as $G_m[n]$ and the last G data samples of the OFDM symbol, i.e., the data samples copied to create the guard interval is defined as $R_m[n]$, then $G_m[n]$ and $R_m[n]$ can be expressed by Equation (4) below.

$$G_m[n] = y_m[n-G]\cdot e^{\frac{j2\pi k_e[n-G]}{N}} \cdot e^{\frac{j2\pi k_e[n+G]}{N}} \cdot e^{jP_e} + W_m[n-G]$$

$$R_m[n] = y_m[n+N-G]\cdot e^{\frac{j2\pi k_e[n+N-G]}{N}} \cdot e^{\frac{j2\pi k_e[n+N+G]}{N}} \cdot e^{jP_e} + W_m[n+N-G] \quad \ldots (4)$$

A detailed description will be made of a carrier synchronizing operation using the guard interval of the first carrier synchronizer 223 in accordance with Equations (2) to (4). The first carrier synchronizer 223 detects phases of the $G_m[n]$ and $R_m[n]$, and calculates a phase difference between the detected phases of $G_m[n]$ and $R_m[n]$. The phase difference between $G_m[n]$ and Rm[n] is expressed by Equation (5) below.

$$\angle G_m[n] = \angle X_m[n-G] + \frac{2\pi k_e[n-G]}{N} + \frac{2\pi k_e m[N+G]}{N} + P_e + \angle W_m[n-G]$$

$$\angle R_m[n] = \angle X_m[n+N-G] + \frac{2\pi k_e[n+N-G]}{N} + \frac{2\pi k_e m[N+G]}{N} + P_e + \angle W_m[n+N-G]$$

$$\begin{aligned}\angle R_m[n] - \angle G_m[n] &= \angle X_m[n+N-G] - \angle X_m[n-G] \\ &\quad + \frac{2\pi k_e[n+N-G]}{N} - \frac{2\pi k_e[n-G]}{N} + \angle W_m[n+N-G] - W_m[n-G] \\ &= 2\pi k_e + \angle W_m[n+N-G] - \angle W_m[n-G] \quad \ldots\ldots\ (5)\end{aligned}$$

In Equation (5), $X_m[n+N+G]$ and $X_m[n-G]$ are the identical signal, so that the phase difference is '0'.

When the phase difference between $G_m[n]$ and $R_m[n]$ is calculated from Equation (5), the first carrier synchronizer 223 calculates an average value of the phase difference using Equation (6) below. The first carrier synchronizer 223 performs carrier synchronization by approximately compensating for the frequency offset of the data input from the ADC 221 based on the calculated average value.

$$k_e = \frac{avg\{\angle R_m[n] - \angle G_m[n]\}}{2\pi} \quad .......(6)$$

Here, if there exists a timing error, there is a case where Equations (2) to (6) are not correct. If the timing error such as an FFT start point detection error and a timing frequency offset is $n_e$, a signal $y'_m[n]$ including the timing error can be expressed by Equation (7) below.

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$$y'_m = y_m[n - n_e]$$

$$= X_m[n - n_e] \cdot e^{\frac{jwpik_e[n-n_e]}{N}} \cdot e^{\frac{j2\pi k_e m[n+G]}{N}} \cdot e^{jP_e} + W_m[n - n_e] \quad ....(7)$$

Here, $y'_m[n]$ includes data samples of the $(m-1)^{th}$ OFDM symbol or the $(m+1)^{th}$ OFDM symbol according to the value of $n_e$. On the above assumption, the phase difference of the respective samples is calculated by Equation (8) below.

$$\angle R_m[n] - \angle G_m[n] = \angle X_m[n + N - G - n_e] - \angle X_m[n - G - n_e]$$

$$+ \frac{2\pi k_e[n + N - G - n_e]}{N} - \frac{2\pi k_e[n - G - n_e]}{N} + \angle W_m[n + N - G - n_e] - W_m[n - G - n_e]$$

$$= 2\pi k_e + \angle W_m[n + N - G - n_e] - \angle W_m[n - G - n_e] \quad .......(8)$$

In Equation (8), $G_m[n]$ and $R_m[n]$ have the values shifted by $n_e$ from their original values, so that the range of $X_m[n+N+G-n_e]$ and $X_m[n-G-n_e]$ becomes $n=n_e, n_e+1, .., G-1$, and $n=0, 1, 2, .., G-n_e-1$ for the negative number. Hence, if an approximate range of the timing error of the system is known, the frequency

offset is calculated in the interval from which the range is excluded. For example, if the maximum timing error does not exceed 'a', the frequency offset can be estimated using Equation (9) below by calculating the phase difference in the interval of n=a, a+1, .., G-a-2, G-a-1, and calculating the average value.

$$k_e = \frac{avg[\angle R_m[n] - \angle G_m[n]]}{2\pi} \quad \ldots\ldots. (9)$$

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Equations (2) to (9) are used when the first carrier synchronizer 223 performs carrier synchronization by estimating the approximate frequency offset. The first carrier synchronizer 223 has the better performance when the used guard interval becomes longer and the timing error of the system has the narrower range. Otherwise, the frequency offset measuring interval becomes shorter, so that the first carrier synchronizer is more affected by the noises and has a difficulty in correctly measuring the frequency offset. After the approximate carrier synchronization, a guard interval remover 225 removes the guard interval from the received data output from the first carrier synchronizer 223 and outputs the guard interval-removed data to a fast Fourier transform (FFT) section 227. The FFT 227 receives the guard interval-removed OFDM symbol, performs the FFT operation on the received OFDM symbol and outputs the original data symbol.

A second carrier synchronizer 229 receives the data symbol FFT-transformed by the FFT 227 and performs fine carrier synchronization on the received data symbol. Specifically, the second carrier synchronizer 229 detects

the pilot symbol of the symbol unit from the data symbol stream, and calculates a phase of the detected pilot symbol. The second carrier synchronizer 229 estimates the fine frequency offset by calculating a phase difference between the calculated phase of the pilot symbol and a known phase of a pilot symbol. After estimation of the fine frequency offset, the second carrier synchronizer 229 performs fine carrier synchronization by compensating for the estimated fine frequency offset.

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An operation of the second carrier synchronizer 229 will be mathematically described below. For the data symbol output from the FFT 227, a frequency offset according to the FFT characteristics is a shift timing error of the signal and is converted to a variation of the phase. This can be expressed by Equation (10) below.

$$\begin{aligned} y'_m[k] &= X_m[k-k_i]\cdot e^{\frac{j2\pi[k-k_i]n_e}{N}}\cdot e^{\frac{j2\pi k_i m[N+G]}{N}}\cdot e^{jP_e}+W_m[k-k_i] \\ &= X_m[k-k_i]\cdot e^{\frac{j2\pi k n_e}{N}}\cdot e^{-\frac{j2\pi k_i n_e}{N}}\cdot e^{-\frac{j2\pi k_i m[N+G]}{N}}\cdot W_m[k-k_i] \quad \ldots\ldots\ldots (10) \end{aligned}$$

where $k_i$ denotes the fine frequency offset.

If only the pilot symbol is detected from the received data, the range of m is 0, l-1, 2l-1, 3l-1, ..., where l denotes a period for inserting the pilot symbol of the symbol unit.

The phase difference of the received pilot symbol is calculated by Equation (11) below.

$$\angle y'_m[k] = \angle X_m[k - k_i] + \frac{2\pi n_e}{N}k - \frac{2\pi n_e k_i}{N} + \frac{2\pi k_i m[N+G]}{N} + P_e + \angle W_m[k - k_i] \quad \ldots (11)$$

In Equation (11), the second term is expressed in terms of a specific variation of the phase according to an index k, the next three terms are expressed in terms of a constant phase offset, and the last term is expressed in terms of a variation of the phase. If the transmitter continuously uses the same pilot symbol and the time error, the common phase error and the frequency offset are identical during the pilot symbol insertion period, then a phase difference between consecutive two pilot symbols $Y_{mpi}'(k)$ and $Y_{mpi+1}$ is calculated by

$$\begin{aligned} diff_{phase} &= \angle y'_{m\pi+1}[k] - \angle y'_{m\pi}[k] \\ &= \angle X_{m\pi+1}[k - k_i] - \angle X_{m\pi}[k - k_i] + \frac{2\pi k_i m_{\pi+1}[N+G]}{N} - \frac{2\pi k_i m_\pi [N+G]}{N} \\ &\quad + \angle W_{m_{\pi+1}}[k - k_i] - \angle W_{m_\pi}[k - k_i] \quad \ldots\ldots\ldots (12) \end{aligned}$$

If the transmitter uses the same pilot symbol as stated above, the first term and the second term have the same value. Hence, Equation (12) can be expressed by Equation (13) below.

$$diff_{phase} = [m_{\pi+1} - m_\pi]\frac{2\pi k_i [N+G]}{N} + \angle W_{m_{\pi+1}}[k - k_i] - \angle W_{m_\pi}[k - k_i]$$

$$= I\frac{2\pi k_i[N+G]}{N} + \angle W_{m_{n+1}}[k-k_i] - \angle W_{m_n}[k-k_i] \quad .......(13)$$

In Equation (13), the first term is expressed in terms of a constant for N samples of one pilot symbol, and the other terms are expressed in terms of a variation due to the noises. Hence, by calculating an average value of the phase differences for N samples, it is possible to obtain the constant of the first term, from which the influence of the noises is almost removed. From this value, it is possible to calculate a fine frequency offset $k_i$ in accordance with Equation (14) below.

$$k_e = \frac{avg\ diff_{phase} \times N}{2\pi[N+G] \times I} \quad .......(14)$$

After calculating the fine frequency offset using Equation (14), the second carrier synchronizer 229 performs carrier synchronization by compensating for a frequency offset of the OFDM symbol based on the calculated frequency offset, and provides its output to a despreader 231. The despreader 231 despreads the fine frequency-synchronized received data.

The detailed structure of the first carrier synchronizer 223 and the second carrier synchronizer 229 will be described with reference to FIGS. 6 and 7. Specifically, FIG. 6 illustrates the detailed structure of the first carrier synchronizer of FIG. 5, and FIG. 7 illustrates the detailed structure of the second carrier synchronizer of FIG. 5.

In FIG. 6, a guard interval detector 301 receives the OFDM symbol stream including the respective guard intervals, output from the ADC 221 of FIG. 5, detects the respective guard intervals $G_m[n]$ included in the OFDM symbol stream, and calculates phases of the respective guard intervals $G_m[n]$. A copied sample detector 303 receives the OFDM symbol stream, detects data samples (hereinafter, referred to as "copied data samples") of the OFDM symbol copied to create the guard intervals $G_m[n]$ to be detected, and calculates phases of the copied data samples. In Equations (2) to (9), the copied data samples are indicated by $R_m[n]$. A phase difference detector 305 calculates phase differences between the data samples of the guard intervals $G_m[n]$ output from the guard interval detector 301 and the copied data samples $R_m[n]$ output from the copied sample detector 303, and outputs the detected phase differences to an averager 307. The averager 307 calculates an approximate frequency offset by averaging the phase differences output from the phase difference detector 305 in a unit of G (=R), and outputs an approximate frequency offset compensation signal to a first frequency offset compensator 309. The first frequency offset compensator 309 receives the OFDM symbol stream including the guard intervals output from the ADC 221, and compensates for the approximate frequency offset of the OFDM symbol stream according to the approximate frequency offset compensation signal output from the averager 307.

In FIG. 7, a pilot symbol detector 311 receives IFFT-transformed received data output from the FFT 227, and detects a pilot symbol included in the

received data. The pilot symbol output from the pilot symbol detector 311 is applied to a delay 312 and a phase difference detector 313. The delay 312 buffers the detected pilot symbol, delays the buffered pilot symbol by the pilot symbol insertion period, and then outputs the delayed pilot symbol to a phase difference detector 313. The phase difference detector 313 receives the pilot symbol detected by the pilot symbol detector 311 and the pilot symbol delayed by the symbol insertion period from the detected pilot symbol, output from the delay 312, calculates phase differences between the corresponding samples of the two pilot symbols, and outputs the calculated phase differences to an averager 314. The averager 314 estimates the fine frequency offset by calculating an average value of the phase differences in the pilot symbol period. After estimation of the fine frequency offset, the averager 314 outputs a fine frequency offset compensation signal for the fine frequency offset to a second offset compensator 315. The second offset compensator 315 receives the FFT-transformed received data from the FFT 327, and compensates for a fine frequency offset of the received data according to the fine frequency offset compensation signal output from the averager 314.

**[EFFECTS OF THE INVENTION]**

As described above, the invention can compensate for a frequency offset even in a situation where the timing error is not compensated for, and increase the accuracy of frequency offset estimation by removing the influence of the variation due to the noises.

**[PATENT CLAIMS]**

1. An apparatus of compensating for a frequency offset using a pilot symbol for a transmitter in an OFDM (Orthogonal Frequency Division Multiplexing), comprising:

a modulator for OFDM-modulating a received data symbol;

a guard interval inserter for inserting a guard interval in the OFDM-modulated data symbol; and

a pilot symbol inserter for inserting a pilot symbol in the data of frame unit output from the guard interval inserter at regular intervals.

2. The apparatus as claimed in claim 1, wherein the pilot symbol inserter punctures one of data symbols of frame unit at regular intervals, and then inserts pilot symbol.

3. An apparatus of compensating for a frequency offset using a pilot symbol for a receiver in an OFDM system for receiving an OFDM signal where a guard interval is inserted to data symbol and inserting a pilot symbol to data of a frame unit at regular intervals, comprising:

a first carrier synchronizer for receiving an data symbol stream where the OFDM signal is converted to digital data and compensating for the approximate frequency offset by detecting the guard interval of each data symbol;

a fast Fourier transform (FFT) section for OFDM-demodulating a signal output from the first carrier synchronizer; and

a second carrier synchronizer for compensating for a fine frequency

offset detecting the pilot symbol after receiving the modulated data symbol stream.

4. The apparatus as claimed in claim 1, wherein the first carrier synchronizer comprises:

a guard interval detector for detecting a guard interval from the data symbol stream;

a copied sample detector for detecting copy samples from the data symbol stream;

a phase difference detector for calculating a phase of the samples of the detected guard interval and a phase of the copied data samples, and calculating a phase difference between the two data samples;

an averager for calculating a frequency error by averaging the phase differences output from the phase difference detector in the frame unit, and outputting a first frequency offset compensation signal according to the frequency offset; and

a first frequency offset compensator for compensating for a frequency offset of the data symbol according to the first frequency offset compensation signal.

5. The apparatus as claimed in claim 3, wherein the second carrier synchronizer comprises:

a pilot symbol detector for detecting a pilot symbol from an OFDM-demodulated data symbol stream;

a delay for delaying the detected pilot symbol by a predetermined time;

a phase difference detector for detecting a phase of the pilot symbol output from the pilot symbol detector and a phase of the delayed pilot symbol output from the delay, and calculating a phase difference between the two pilot symbols;

an averager for calculating a fine frequency offset by averaging the phase differences in a frame unit and outputting a second frequency offset compensation signal according to the fine frequency offset; and

a second frequency offset compensator for compensating for a fine frequency offset of the demodulated data symbol according to the second frequency offset compensation signal.

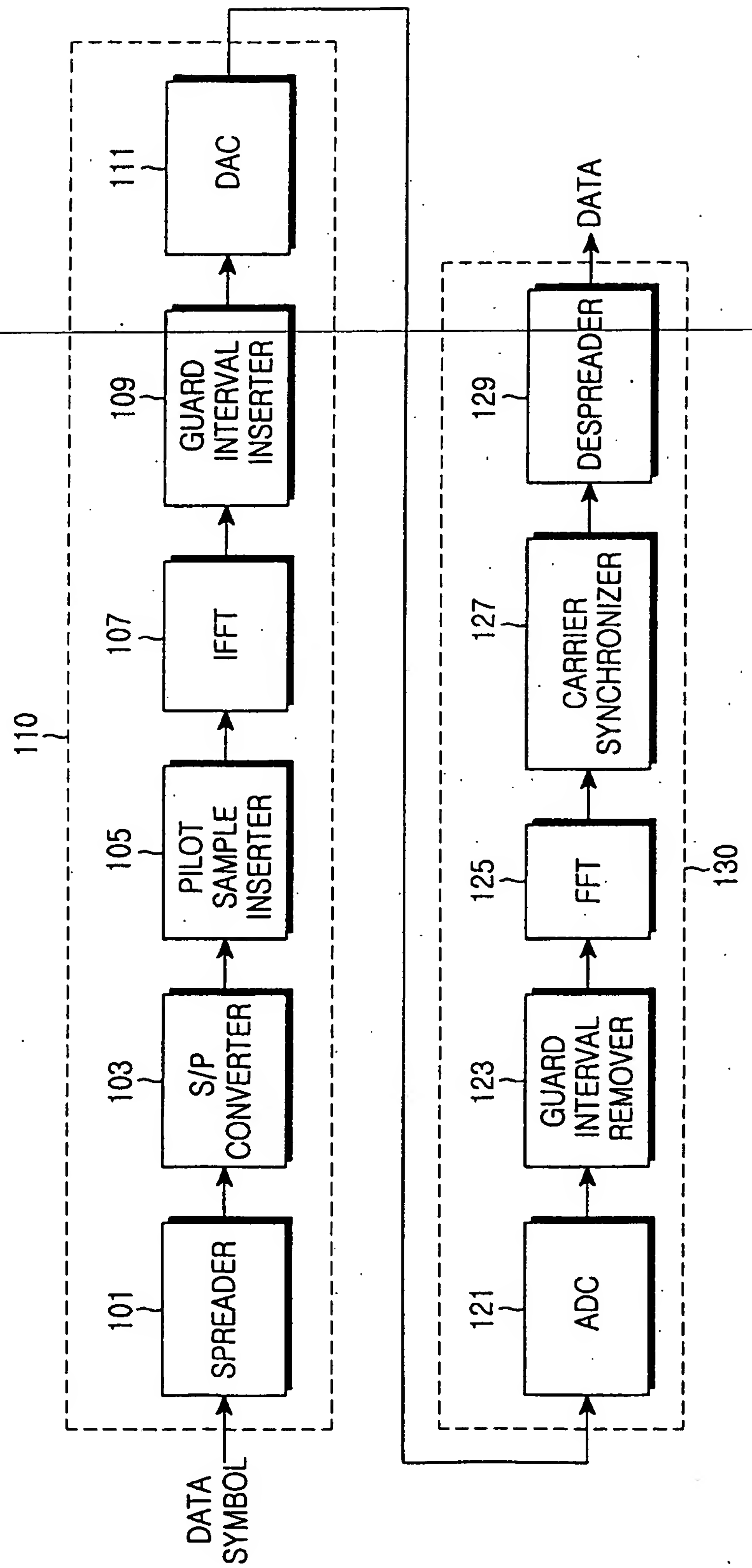

DATA SYMBOL
110
101
SPREADER
103
S/P CONVERTER
105
PILOT SAMPLE INSERTER
107
IFFT
109
GUARD INTERVAL INSERTER
111
DAC
130
121
ADC
123
GUARD INTERVAL REMOVER
125
FFT
127
CARRIER SYNCHRONIZER
129
DESPREADER
DATA

FIG.1

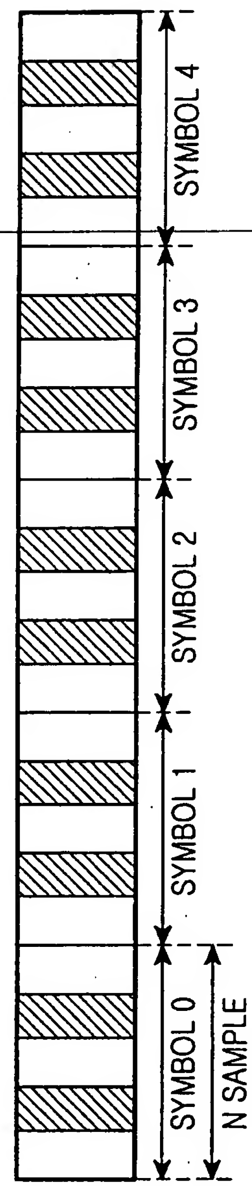
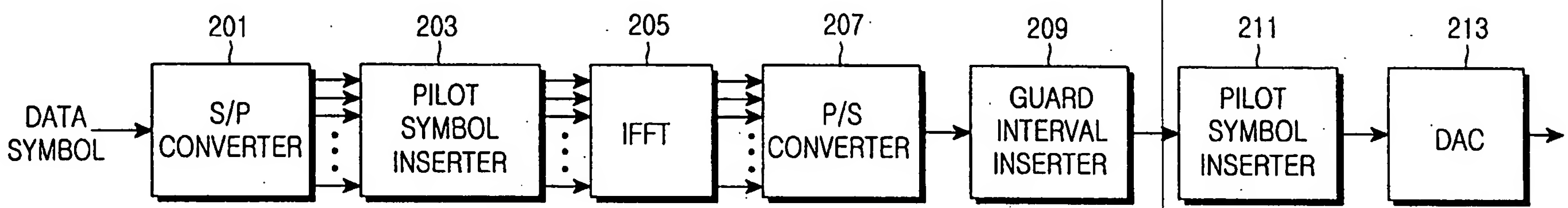



FIG.2



DATA SYMBOL
201
S/P CONVERTER
203
PILOT SYMBOL INSERTER
205
IFFT
207
P/S CONVERTER
209
GUARD INTERVAL INSERTER
211
PILOT SYMBOL INSERTER
213
DAC


FIG.3

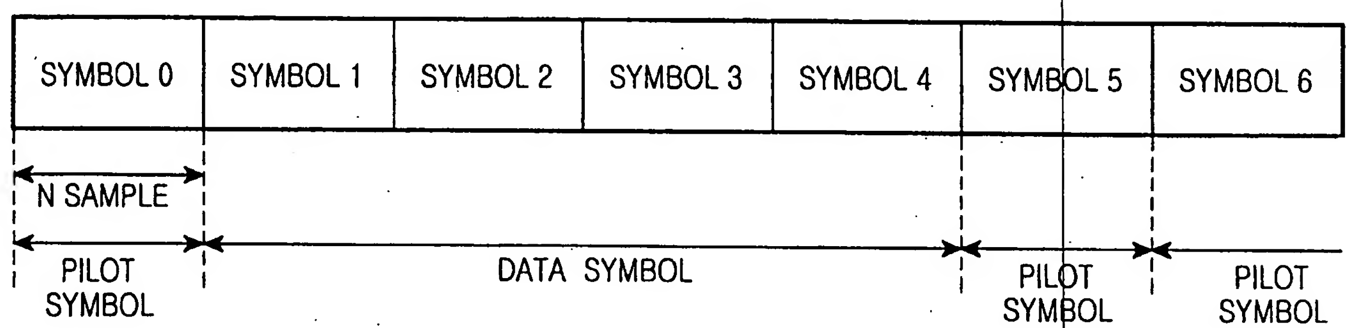

SYMBOL 0
SYMBOL 1
SYMBOL 2
SYMBOL 3
SYMBOL 4
SYMBOL 5
SYMBOL 6
N SAMPLE
PILOT SYMBOL
DATA SYMBOL
PILOT SYMBOL
PILOT SYMBOL

FIG.4

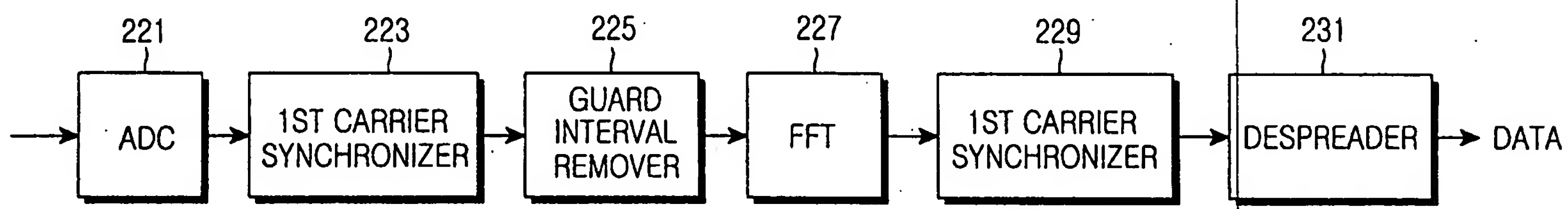

221
223
225
227
229
231
ADC
1ST CARRIER SYNCHRONIZER
GUARD INTERVAL REMOVER
FFT
1ST CARRIER SYNCHRONIZER
DESPREADER
DATA

FIG.5

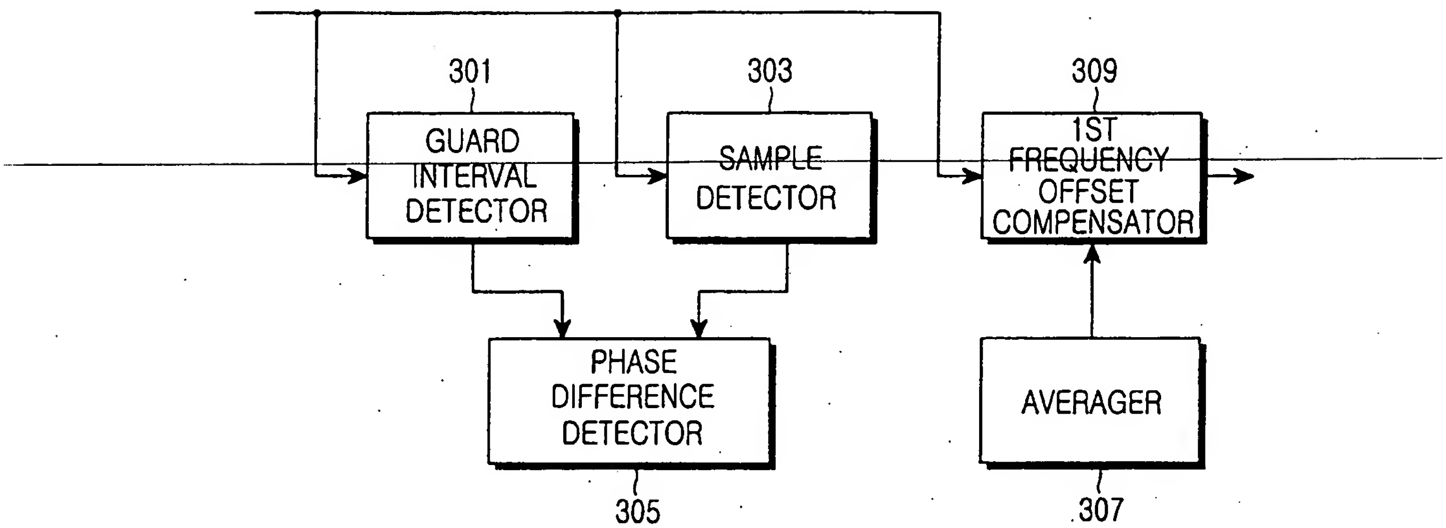
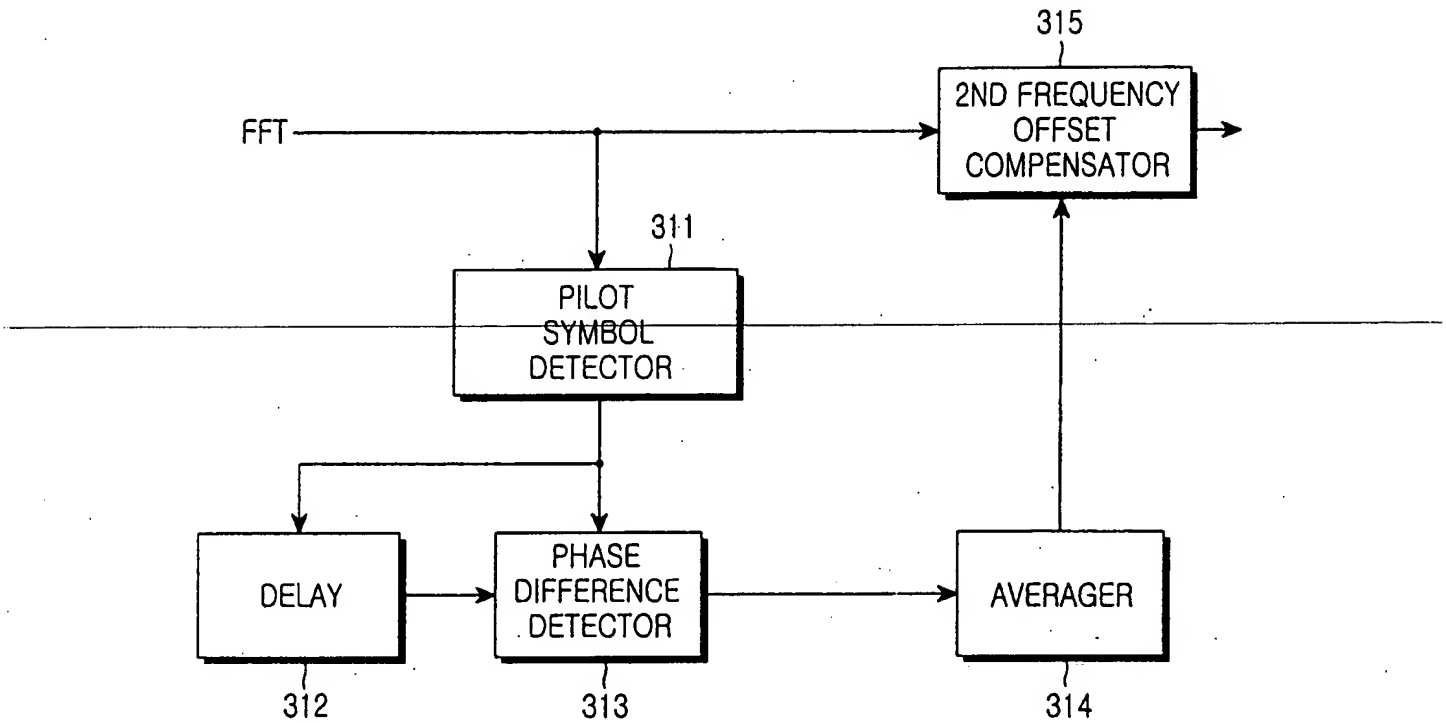

301
GUARD INTERVAL DETECTOR
303
SAMPLE DETECTOR
309
1ST FREQUENCY OFFSET COMPENSATOR
PHASE DIFFERENCE DETECTOR
305
AVERAGER
307

FIG.6



315
FFT
2ND FREQUENCY OFFSET COMPENSATOR
311
PILOT SYMBOL DETECTOR
DELAY
PHASE DIFFERENCE DETECTOR
AVERAGER
312
313
314


FIG.7